

Fertility among Female Survivors of the Atomic Bombs of Hiroshima and Nagasaki

WILLIAM J. BLOT¹ AND HISAO SAWADA²

INTRODUCTION

Studies to determine both acute and latent effects of the atomic bombs of Hiroshima and Nagasaki upon pregnancy outcome and fertility have been conducted in Japan. The Joint Commission for the Investigation of the Atomic Bomb reported reduced sperm counts and histological gonadal changes in fatal cases in those proximally exposed to the atomic bombs [1]. Yamazaki et al. [2], in examining the outcomes of pregnancies of Nagasaki women who were pregnant at the time of the bomb, found excessive fetal loss and infant mortality among those who were heavily exposed and evidenced major radiation symptoms. During the years 1948-1953, Neel and Schull [3] considered some 70,000 pregnancy terminations in the two cities. Testing several genetic hypotheses, they found no evidence of differences in frequencies of congenital malformations, stillbirths, or neonatal deaths among groups of parents of varying degrees of radiation exposure.

In a study of fertility over the 16-year period 1945-1961, Seigel [4] consulted the Japanese official family-registration records and found no significant differences in the ratios of numbers of live births to years of marriage among individuals divided into groups according to distance from the hypocenters of the atomic explosions of 1945.

The study reported herein likewise examines fertility over a relatively long period of time (up to 18 years). However, considerably more detailed information is available allowing the calculation of rates of pregnancy and allowing for the inclusion of certain factors, notably the practice of contraception, which may influence these rates. In addition, a system of dosimetry [5] has evolved through which individual radiation dose estimates can be assigned to almost every member of the sample under study. Utilizing this dosimetry to define comparison groups, the object of this study has been to determine whether the likelihood of conception has been significantly altered by exposure to atomic radiation.

Received August 17, 1971; revised February 14, 1972.

¹ Department of Statistics, Atomic Bomb Casualty Commission (a cooperative research agency of the U.S. National Academy of Sciences-National Research Council and the Japanese National Institute of Health of the Ministry of Health and Welfare, with funds provided by the U.S. Atomic Energy Commission, the Japanese National Institute of Health, and the U.S. Environmental Protection Agency), U.S. Marine Corps Air Station, FPO Seattle, Washington 98764.

² Department of Medicine, Atomic Bomb Casualty Commission, Hiroshima, and Hiroshima Branch, Japanese National Institute of Health, Hiroshima, Japan.

© 1972 by the American Society of Human Genetics. All rights reserved.

METHODS

Married women of various ages and backgrounds were interviewed concerning their reproductive histories (see questionnaire listed in fig. 2). The interviews were conducted as part of regularly scheduled biennial visits of members of the Japanese National Institute of Health-Atomic Bomb Casualty Commission (JNIH-ABCC) Adult Health Study Program (AHS) [6] in Hiroshima and Nagasaki during the years 1962-1964. All women of the AHS who were between the ages of 8 and 40 at the time of the bomb who came to the ABCC clinics were interviewed. Those who had been divorced, separated, sterilized, or for whom there was no estimate of radiation dose received from the atomic explosions were not considered. Reproductive experiences of first marriages only were taken into account. The sample so selected consisted of a total of 2,345 Hiroshima and Nagasaki women.

Data for those who were married after the bomb (AB) were analyzed separately from those married before the bomb (BB). The entire marriage experience of the former, to be called the AB sample, was necessarily conducted after their exposure to radiation, whereas many of the latter, to be called the BB sample, had conceived and delivered one or more children prior to their exposure. Since our interest lies in determining possible radiation effects, only those pregnancies in which fertilization was believed to have taken place after August 1945 were considered for this latter sample.

Individuals in the samples were classified according to their length of marriage in the postwar years. The end point of marriage time was taken to be the earliest of the following: date of interview, onset of menopause, or end of marriage. Only those women whose marriage length extended for at least 3 years were considered. For the AB sample, two marriage-length categories were defined, encompassing those married more than 10 years and those married 10 years or less. For the BB sample, individuals were grouped by the number of children born (parity) before the bomb rather than length of postwar marriage. This sample was also divided into two age categories. Those aged 35-39 in August 1945, thought of as being of marginal fertility, were treated separately.

A particularly relevant factor in assessing an individual's fertility (but difficult to accurately quantify) is the practice of contraception. Based on answers to indirect questions (see fig. 2), both the AB and BB samples were divided into two sections. One, designated as the C- group, consisted of those who did not admit to practicing contraception at any time after August 1945. The other, designated as the C+ group, consisted of those who did. As will be seen from tables 1 and 2, contraception was widely practiced, more so in Hiroshima than Nagasaki.

The final classification within the samples was according to total radiation dose received from the atomic bombs. The women interviewed were classified into one of the following four radiation dose groups (labeled "T65 dose" in [5]): not in city (NIC), 0-9 rad, 10-99 rad, and 100 or more rad (100+).

Tables 1 and 2 list the numbers of women in the divisions of the two samples by city, practice of contraception, marriage length or parity, and T65 radiation dose.

The fertility of these individuals will be defined in terms of the likelihood of conception. The measure to be considered is the pregnancy rate. Originally proposed by Pearl [7], the rate of pregnancy, R , is defined by

$$R = \frac{\text{no. pregnancies}}{\text{no. years exposure to conception}} \times 100.$$

The number of years exposure to conception is given by the number of months of marriage after August 1945 minus the elapsed time, in months, during which conception is believed to be physiologically impossible, divided by 12. To obtain this conception-exposure time, the time spent in pregnancy was subtracted from total marriage time. Time spent in

TABLE 1

NUMBERS OF WOMEN INTERVIEWED MARRIED AFTER AUGUST 1945 ACCORDING TO CITY,
PRACTICE OF CONTRACEPTION, MARRIAGE LENGTH, AND RADIATION DOSE

CITY AND CONTRACEPTION PRACTICE		MARRIAGE LENGTH (YEARS)	Dose (rad)				Total
			NIC*	0-9	10-99	100+	
Hiroshima:							
Yes	{ 3-10	47	77	60	29	213	
	{ 11-18	77	75	51	31	234	
No	{ 3-10	42	77	63	17	199	
	{ 11-18	65	66	36	27	194	
Total	{ 3-10	89	154	123	46	412	
	{ 11-18	142	141	87	58	428	
Nagasaki:							
Yes	{ 3-10	19	32	6	20	77	
	{ 11-18	29	32	8	41	110	
No	{ 3-10	44	49	19	52	164	
	{ 11-18	38	27	21	62	148	
Total	{ 3-10	63	81	25	72	241	
	{ 11-18	67	59	29	103	258	

* NIC = not in city.

postpartum lactation was not excluded from exposure time. In calculating R , all pregnancies, including those ending in spontaneous and induced abortion, were considered.

Pregnancy rates were calculated for each person in the two samples. A linear statistical model containing parameters representing contraception, marriage length or parity, and radiation-dose-group differences was used to describe the individual pregnancy rates for members of the sample in each city. Analysis of variance techniques were used to determine whether the parameters of the models associated with dose differences were significantly different from zero, that is, to see if differences among the dose groupings did in fact exist. In some cases, the variable of interest was not the pregnancy rate but a percentage of individuals with a certain attribute (e.g., those with zero pregnancies). For such cases, statistical tests employing contingency tables of dose versus percentage were conducted to see if the percentages varied with dose.

RESULTS

One of the first questions asked was whether those in the high-radiation-dose groups (100+ rad) were sterile in comparison with the remaining groups. The answer appears to be no. Within each contraceptive-practice group, there were no significant* differences among the dose groups in the proportions who failed to conceive in the postwar years for both samples and both cities. These percentages are listed in table 3. Because of the small numbers of individuals, data from the Nagasaki 10-99 rad group are not listed.

Highly significant differences were found between the C+ and C- groups.

* Throughout this paper, the terms "significant" and "highly significant" will refer to statistical significance at the .05 and .01 levels, respectively.

TABLE 2

NUMBERS OF WOMEN INTERVIEWED MARRIED BEFORE AUGUST 1945 ACCORDING TO AGE,
CITY, PRACTICE OF CONTRACEPTION, PARITY, AND RADIATION DOSE

CITY, AGE IN 1945, AND CONTRACEPTION PRACTICE	PARITY IN 1945	DOSE (rad)				Total
		NIC*	0-9	10-99	100+	
Hiroshima (<35):						
Yes	{ 0, 1	19	22	21	10	72
	{ 2+	12	20	15	6	53
No	{ 0, 1	35	65	67	20	187
	{ 2+	61	83	63	19	226
Total	{ 0, 1	54	87	88	30	259
	{ 2+	73	103	78	25	279
Nagasaki (<35):						
Yes	{ 0, 1	5	5	1	2	13
	{ 2+	5	5	1	2	13
No	{ 0, 1	17	15	13	20	65
	{ 2+	9	17	15	17	58
Total	{ 0, 1	22	20	14	22	78
	{ 2+	14	22	16	19	71
Hiroshima (35-39):						
Total .....	...	64	105	70	31	270
Nagasaki (35-39):						
Total .....	...	12	17	8	12	49

* NIC = not in city.

Whereas sizable numbers of those who did not practice contraception (C— group) had sterile marriages, nearly everyone who did practice contraception at some time (C+ group) conceived at least once following exposure to the bomb. Within the C— groupings, the percentages were consistently larger in Hiroshima than Nagasaki, significantly so for those in the AB sample married 11-18 years and those in the 0, 1 parity group of the BB sample. The city difference was most striking for those aged 35-39 at the time of the bomb. For individuals of that group, over 60% in Hiroshima, but less than 30% in Nagasaki, failed to conceive after August 1945. Differences between marriage-length groups fell short of significance. The direction of parity differences depended upon whether contraception was practiced.

Finding no large differences due to radiation in the percentages of those with sterile marriages, and hence with pregnancy rates equal to zero, an attempt was made to determine whether differences in pregnancy rates existed for those who conceived at least once. Figure 1 shows a relative-frequency histogram of these pregnancy rates for the Hiroshima AB sample. Since distributions of the pregnancy rates for those with at least one pregnancy were similar for the C+ and C— groups, in contrast to the noticeable differences in the proportions of women with

TABLE 3

PERCENTAGES OF WOMEN WITH NO PREGNANCIES AFTER AUGUST 1945 ACCORDING TO
DATE OF MARRIAGE, AGE, CITY, PRACTICE OF CONTRACEPTION, MARRIAGE
LENGTH OR PARITY, AND RADIATION DOSE

CITY, AGE IN 1945, AND CONTRACEPTION PRACTICE	MARRIAGE LENGTH OR PARITY	DOSE (rad)				Total
		NIC*	0-9	10-99	100+	
Marriage after August 1945						
Hiroshima (<35):						
Yes	{ 3-10 11-18	0 0	1.3 0	1.7 0	0 0	0.9 0
No	{ 3-10 11-18	9.5 12.3	13.0 12.1	12.7 13.9	17.6 7.4	12.6 11.9
Nagasaki (<35):						
Yes	{ 3-10 11-18	0 0	0 0	... ...	0 0	0 0
No	{ 3-10 11-18	9.1 7.9	10.2 0	... ...	5.8 4.8	8.3 4.7
Marriage before August 1945						
Hiroshima (<35):						
Yes	{ 0, 1 2+	0 8.3	0 10.0	0.0 13.3	0 0	0 9.4
No	{ 0, 1 2+	34.3 26.2	30.8 19.3	37.3 20.6	45.0 26.3	35.3 22.1
Nagasaki (<35):						
Yes	{ 0, 1 2+	0 0	0 0	... ...	0 0	0 0
No	{ 0, 1 2+	23.5 22.2	13.3 6.3	... ...	15.0 11.8	17.3 11.6
Hiroshima (35-39):						
Total .....	...	60.9	61.0	65.7	61.3	62.2
Nagasaki (35-39):						
Total .....	...	25.0	35.3	37.5	16.7	26.5

* NIC = not in city.

zero pregnancies, the data for the two contraception groups are combined in figure 1.

Because of the form of the distribution of pregnancy rates greater than zero, the analyses of variance for testing radiation effects were not performed on the actual R 's themselves, but on transformed values of R . An arcsin square-root transformation was employed. The transformation was applied to individual values of the number of pregnancies per years of exposure to conception. Because of a large number of high values (R levels greater than 100), the transformation was applied to the number of pregnancies per half years of exposure to conception for the AB sample.

For both the AB and BB samples and for both Hiroshima and Nagasaki, the

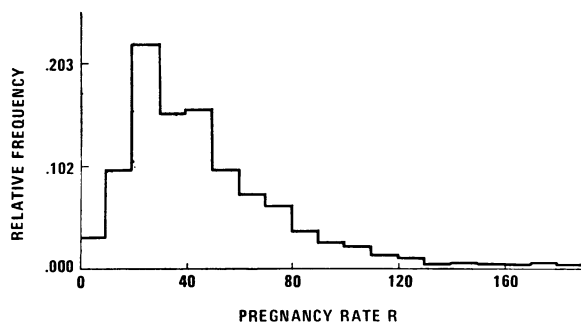


FIG. 1.—Relative-frequency histogram of positive values of the pregnancy rate R , Hiroshima AB sample.

analyses of variance on the transformed rates showed no significant dose effect. There were no consistent patterns indicating any reduction in the likelihood of conception among those who had received high doses of atomic radiation.

Table 4 lists average values of the untransformed rates R according to marriage sample, marriage length or parity, and T65 dose group. The analyses of variance uncovered no significant effect of the practice of contraception, and hence the data from the C+ and C— groups are combined in the table. In the AB sample, marriage-length differences were highly significant in both cities, those married 3–10 years having larger rates than those married 11–18 years. Parity differences in the BB sample were highly significant in Hiroshima, those with either zero or one child prior to the bombs having larger average rates. The R 's were uniformly higher in Nagasaki than Hiroshima. In both samples, the overall Nagasaki means were highly

TABLE 4

MEAN PREGNANCY RATES FOR INDIVIDUALS WITH AT LEAST ONE PREGNANCY AFTER AUGUST 1945 ACCORDING TO DATE OF MARRIAGE, CITY, MARRIAGE LENGTH OR PARITY, AND RADIATION DOSE

CITY	MARRIAGE LENGTH OR PARITY	Dose (rad)				Total
		NIC*	0-9	10-99	100+	
Marriage after August 1945						
Hiroshima	{ 3-10	66.7	55.3	57.2	55.8	58.4
	{ 11-18	35.6	34.7	37.1	38.1	36.0
Nagasaki	{ 3-10	75.6	68.7	...	74.7	72.7
	{ 11-18	48.7	43.9	...	45.5	46.0
Marriage before August 1945						
Hiroshima	{ 0, 1	21.1	21.0	24.0	22.2	22.1
	{ 2+	16.4	15.7	15.0	23.4	16.3
Nagasaki	{ 0, 1	29.5	35.8	...	35.7	33.7
	{ 2+	26.9	38.5	...	28.1	32.2

* NIC = not in city.

significantly larger than the Hiroshima means for both marriage length and parity groups.

Since the analyses of variance were conducted on transformed values, we cannot exactly determine the magnitude of actual differences among the dose group means of the untransformed pregnancy rates that could be detected by the analyses of variance. However, by inversely transforming, we can obtain conservative estimates of these sizes. With at least 80% probability, if there existed differences of roughly 15 or more in the mean values of R for the radiation dose groups for the AB sample, or roughly 10 and 17 for Hiroshima and Nagasaki, respectively, in the BB sample, they would have been detected.

DISCUSSION

The intent of this study has been to determine if exposure to the atomic bombs of 1945 has impaired subsequent likelihood of conception over a period of time extending through 1962–1964. Previous related studies by Neel and Schull [3], examining pregnancy outcome over a 5-year span beginning 3 years after the bombs, and by Seigel [4], examining birth rates through 1961, both were negative in the sense that no significant radiation effects were reported. In view of these previous negative findings, it was not expected that our study would uncover any latent radiation effects. It was nevertheless felt that the information available to us, which included detailed reproductive histories and complete individual radiation-exposure estimates, indeed warranted analysis.

The present analyses did corroborate the results of the earlier studies. Combining all results, it is apparent that no large long-range alterations in average fertility can be attributable to exposure to atomic radiation in 1945.

The significant differences in fertility according to city, practice of contraception, and marriage length and parity that were found indicate that inclusion of these concomitants was necessary. Our results showing higher fertility in Nagasaki were consistent with those of Taeuber's [8] study of the population of Japan rather than with Seigel [4], who reported no such difference. Taeuber [8], as we have, noted differences in sterility (in 1952 and 1954) between those who admitted practicing contraception and those who did not, suggesting that the practice was generally adopted following conception (and birth). In the AB sample, a large majority, 82%, began practicing contraception after the year of their first pregnancy.

A conjecture that had been raised was that those in the high-dose groups, fearing unknown atomic bomb effects, might not want to produce offspring. This conjecture was not supported by the data. In fact, of the entire sample interviewed, only 10 indicated they were reluctant to have children because they feared the consequences of the bomb. No evidence of differing contraception practice according to dose was noted.

Since the purpose of this study has been the investigation of possible radiation effects, comparisons of our data with outside sources has not been sought. In effect we have compared a high-dose group (100+ rad) with three internal "controls":

those not in city, those in city with low (0–9 rad) doses, and those in city with 10–99 rad doses. When nonradiation differences such as city, practice of contraception, and marriage length or parity are taken into account, we feel these control groups represent the most adequate groups for comparison presently available. (Socioeconomic information was not obtained during the interviews. However, Neel and Schull [3] found no clear evidence of differing economic status in the postwar years according to radiation exposure group.)

The doses used to define the comparison groups were doses received by the interviewees. Accurate dose estimates for their husbands could not be obtained. From T65 dose estimates for the parents of 50,000 children, members of the ABCC F₁ sample born during the years 1946–1958, including many in Neel and Schull's [3] study, a highly significant correlation between T65-radiation-exposure groupings of husbands and wives (fathers and mothers) was evident. Hence, possible differences in fertility due to radiation should in fact be more pronounced than if the husbands' exposures were uniform throughout the four comparison groups.

The accuracy of the interviewees' memories is a problem of concern, since histories were obtained for reproductive experiences over periods of up to 18 years. To ascertain the reliability of the present information for a subsample of our population, references were made to charts from clinical examinations conducted four years earlier at ABCC which recorded the numbers of births and abortions. (Dates were not available nor were induced abortions differentiated from spontaneous abortions.) For over one-third of this subsample, the information obtained at the two different times failed to match. However, the inconsistencies nearly always showed our interviews reporting a higher number of pregnancies than earlier. These differences were mostly due to the inclusion of induced abortions which had been omitted at the first examination. Hence, though we cannot make any statements about the accuracy of our anamnestic histories in absolute terms, it does appear our data were substantially more reliable relative to that obtained earlier.

In the method of analysis employed, a fertility index (R) was determined for each member of the sample. Averages of these rates were computed, and comparisons of averages of the various dose groups were then made. An alternative method, perhaps more commonly used in the literature, considers fertility indices for groups of individuals. A separate measure is not constructed for each person, but rather the aggregate experience of groups of persons are compared. Hence, a group pregnancy rate is formed by summing the number of pregnancies for all persons in that group and then dividing by the sum of marriage-exposure years of all persons in the group. We feel the first method is more appropriate in that it considers direct measures of each person's fertility. However, we also applied the alternative method. The conclusions remained unchanged.

SUMMARY

Information concerning the reproductive histories of 2,345 Hiroshima and Nagasaki women subject to varying degrees of radiation exposure from the atomic bombs of 1945 was obtained from personal interviews. From this information, the

Atomic Bomb Casualty Commission 原爆傷害調査委員会		RESEARCH PROJECT FORM 研究課題書式																
Place of Examination 診療場所 Hiroshima 広島 Nagasaki 長崎																		
Project Title 研究題目 FERTILITY STUDY 出産力調査																		
Family Name 姓		Given Name 名 漢字及びふりがな																
Investigator 調査者 SAWADA ET AL.		Sex M 男 <input type="checkbox"/> F 女 <input type="checkbox"/>	Age 年齢															
Date of Record 調査年月日																		
Birth Date: Patient 対象者		Present Spouse 現在の配偶者																
Prior 1 1の以前		Prior 2 2の以前																
Marriage 婚姻状態	Spouse's Name (Maiden name if pertinent) 配偶者の氏名 (必要ときは結婚前の氏名)	Dates of Marriage 婚姻年月日																
		Began 自	Ended 至															
		Day Mo. Yr.	Day Mo. Yr.															
		日 月 年	日 月 年															
		Long Separation (1 year or more) 長期の別居 (1年以上)																
		From 自	To 至															
		日 月 年	日 月 年															
		Location of spouse ATB (address if known) 原爆投下時に配偶者のいた地点 (所在地が判っていれば記入)																
Present 1. 現在																		
Prior 1 2. 1の以前																		
Prior 2 3. 2の以前																		
All Pregnancies 現在までの妊娠歴		Number of Pregnancies 妊娠回数																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Date of Termination 終結年月日	Month 月																	
	Year 年																	
Termination 終 結	Living 生存																	
	Stillbirth 死産																	
	Spontaneous 自然 Abortion 流産																	
	Induced Abortion 人工流産																	
Duration of Pregnancy in Months 妊娠が続いた月数																		
Weight at Birth 出生時体重 kgm																		
Age at Death 死亡年齢																		
Additional History 付属事項																		
1. Did parents wish to have more children? Yes <input type="checkbox"/> No <input type="checkbox"/> 両親はもっと子供を作りたいと思ったことがあるか。はい いいえ																		
If no, state reason 1. _____ 思わない場合は _____ その理由を記すこと 3. _____																		
2. Have there been unsuccessful efforts to have more children? Yes <input type="checkbox"/> No <input type="checkbox"/> もっと子供を作りたいと努力したが不成功に終わったか。はい いいえ																		
If yes, when From 自 _____ Yr. 年 To 至 _____ Yr. 年 もし不成功に終わったのなら, From 自 _____ Yr. 年 To 至 _____ Yr. 年 それはいつか, From 自 _____ Yr. 年 To 至 _____ Yr. 年																		
3. Have there been periods when no efforts were made to have children? Yes <input type="checkbox"/> No <input type="checkbox"/> 子供を作る努力をしない時期があったか。はい いいえ																		
If yes, when From 自 _____ Yr. 年 To 至 _____ Yr. 年 もしあるのなら, From 自 _____ Yr. 年 To 至 _____ Yr. 年 それはいつか, From 自 _____ Yr. 年 To 至 _____ Yr. 年																		
4. Has either parent been sterilized? Patient Yes <input type="checkbox"/> No <input type="checkbox"/> Yr. 年 両親のどちらかが不妊手術を受けているか。対象者 はい いいえ																		
Spouse Yes <input type="checkbox"/> No <input type="checkbox"/> Yr. 年 配偶者 はい いいえ																		

MARITAL AND FERTILITY RECORD
婚姻と出産力の記録

ME-D53 162

FIG. 2.—Pregnancy history questionnaire

likelihood of conception over a span of years from immediately following exposure through nearly 2 decades later was calculated. Significant differences in percentages of marriages without conception according to practice of contraception and city of residence were found. Significant differences in rates of pregnancy by city, marriage length, and parity were also shown. However no evidence that exposure to high doses (100+ rad) of atomic radiation has impaired subsequent fertility was uncovered.

REFERENCES

1. OUGHTERSON A, WARREN S: *Medical Effects of the Atomic Bomb in Japan*. New York, McGraw Hill, 1956
2. YAMAZAKI JN, WRIGHT SW, WRIGHT PM: Outcome of pregnancy in women exposed to the atomic bomb in Nagasaki. *Amer J Dis Child* 87:448-463, 1954
3. NEEL JV, SCHULL WJ: The effect of exposure to the atomic bomb on pregnancy termination in Hiroshima and Nagasaki, National Academy of Sciences-National Research Council, Publication no. 461, 1956
4. SEIGEL D: Frequency of live births among survivors of the atomic bombs Hiroshima and Nagasaki. *Radiat Res* 28:278-288, 1966
5. MILTON RC, SHOHOJI T: Tentative 1965 radiation dose estimation for atomic bomb survivors, Hiroshima and Nagasaki. Atomic Bomb Casualty Commission TR 1-68, 1968
6. Atomic Bomb Casualty Commission-Japanese National Institute of Health: ABCC-JNIH Adult Health Study, Hiroshima-Nagasaki, Research Plan, ABCC TR 11-62, 1962
7. PEARL R: Contraception and fertility in 2,000 women. *Hum Biol* 4:363-407, 1932
8. TAEUBER IB: *The Population of Japan*. Princeton, N.J., Princeton Univ. Press, 1958

Sheba International Symposium Genetic Polymorphisms and Diseases in Human Populations

A symposium to commemorate the late Prof. Chaim Sheba will be held March 18-22, 1973, at Tel-Aviv University in Tel Aviv, Israel. Invited speakers will deal with the following topics: polymorphic traits, genetic isolates, screening, genetic diseases in populations, and recent advances in selected topics of medical genetics.

For further information contact Dr. B. Ramot, Chaim Sheba Medical Center, Tel-Hashomer, Israel.